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Coop Progress Report

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Coop Progress Report*

Profile

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Abstract

My Coop at LLNL has been my first professional experience as an Electrical Engineer. I was tasked to carry out signal processing to analyze data and code in the IDL following standard software development principles. The Coop has met all of my needs to continue my professional career, and I feel more confident as I continue working as a student and professional. It is now a big open question for me as whether to pursue graduate research or industry after I graduate with my B.S. in Electrical Engineering.

Project overview

NIF is a multi-billion dollar program chartered by the Department of Energy (DOE) to achieve the goal of using lasers in a laboratory setting. A key characteristic of the ignition experiments is to generate neutrons. Understanding the spatial distribution of neutron flux radially emitted is critical. There are ~20 flange neutron activation detectors (FNADs) located around the NIF spherical target chamber to measure neutrons. My project consists of developing the data analysis to reconstruct the 3D neutron distribution and code the software such that it automatically processes the FNAD data immediately after an ignition-type experiment occurs.

List of Outcomes

1. Constructed a 3D neutron yield distribution that is fit through a sparse set of measurements around a 10-m diameter spherical target chamber.
2. Coded two production-quality IDL software routines that run in an automated production setting

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3. Constructed various plots of the analysis results that are displayed on a NIF internal website for scientific review.

Method/Results

In order to estimate the 3D neutron yield distribution around the target chamber, we calculate the neutron yield at each detector location using the following equation,

$$Y_i = \frac{A_{0,i}}{p_{rx}} \varepsilon_{irr,i} \quad (1)$$

Here $A_{0,i}$ is the initial activity product nuclei formed at time $t = 0$ at detector location i , $\varepsilon_{irr,i}$ (irradiation efficiency) is the fraction of neutron born at the target chamber within the subtended solid angle, and p_{rx} is the reaction probability with activation foil per neutron born at the target chamber. The reaction probability is defined by,

$$p_{rx} = \frac{N_{target}}{4\pi R^2} \int_E \frac{dn}{dE} \sigma(E) dE \quad (2)$$

where N_{target} is the number of target nuclei in activation foil, R is the radius of the target chamber, and n is the number of neutrons emitted from target chamber center. The integral in Equation (2) is convolving a Gaussian neutron spectrum in energy space with a detector-dependent ($n, 2n$) scattering cross-section, $\sigma(E)$.

Given the yield at each location, we decided to use a spherical harmonic basis set to fit the yield data points to estimate a neutron distribution as a function of azimuthal and elevation angle. A spherical harmonic is the product of a Legendre function with a Fourier function and is a natural basis choice for data points located on a spherical surface. Although the basis functions are non-linear, the fit of the basis functions to the data is a linear problem. Specifically, the following equation identifies the optimization problem of interest:

$$\arg \min_{\mathbf{c}} \|\mathbf{y} - \mathbf{H}\mathbf{c}\|^2 \quad (3)$$

where \mathbf{y} is a vector of yields from all detectors, \mathbf{H} is the spherical harmonic matrix, and \mathbf{c} is a vector of the unknown fit coefficients. Every column of \mathbf{H} is a particular (l, m) mode of the spherical harmonic. Clearly the number of basis functions is limited by one minus the number of detectors. The solution to (3) can be shown to be:

$$\mathbf{c} = (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \mathbf{y} \quad (4)$$

There are many ways to computationally solve for the unknown fit coefficients. We decided to decompose \mathbf{H} using the Singular Value Decomposition (SVD) into two orthogonal matrices, \mathbf{U} and \mathbf{V} , and a diagonal matrix, $\mathbf{\Sigma}$ (see Equations 5). Replacing Eq. 5 into Eq. 4, the solution to (3) now is Eq. 6.

$$\mathbf{H} = \mathbf{U} \mathbf{\Sigma} \mathbf{V}^T \quad (5)$$

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$$\mathbf{c} = \mathbf{V} \mathbf{\Sigma}^{-1} \mathbf{U}^T \mathbf{y} \quad (6)$$

In order to demonstrate the utility of the methods just described, we show an example using real experimental data acquired approximately 2 years ago. For this example, there are 10 detector locations, and four spherical harmonic basis functions were employed: $(l,m) = \{(0,0), (1,-1), (1,0), (1,1)\}$. Figure 1a below shows the 3D fit to the data points as a sinusoidal projection. Two lineouts along $\cos(\theta)$ and φ are shown in Figures 1b and 1c.

Once calculated all of the above terms, we constructed the 3D neutron yield distribution image below (Figure 1.a),

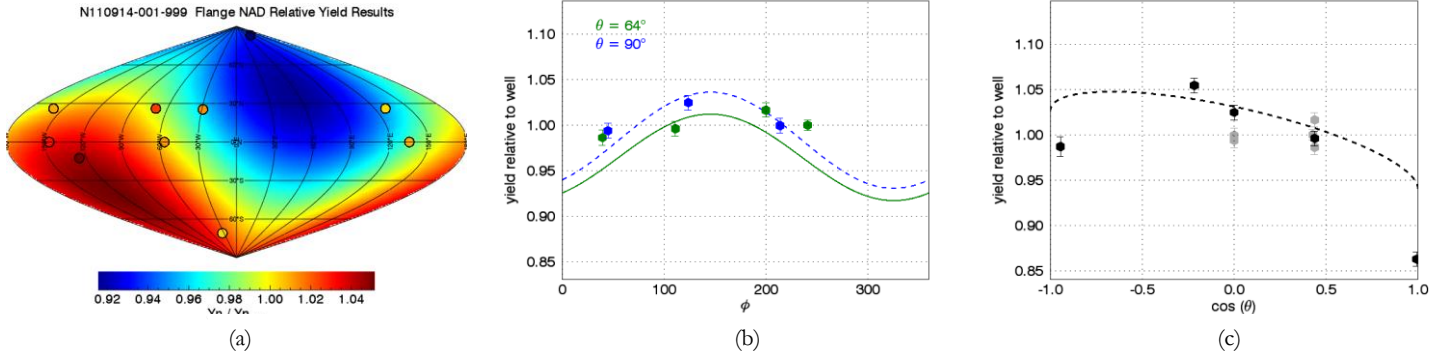


Figure 1: (a) 3D neutron distribution yield estimate, (b) lineouts through two θ angles, (c) lineout through $\varphi=120^\circ$

The analysis method described above was coded in the IDL language and partitioned into two analysis modules. The first module computes the yield for each detector location and therefore is a many-to-many mapping. The second module calculates the 3D surface fit and therefore is a many-to-one mapping. The two analysis modules have been automated in a Production framework such that the raw data, calibration data, and analysis parameters are automatically retrieved from various databases and output results are automatically archived in a database. Results can be viewed on an internal website. Figure 2 below illustrated the process.

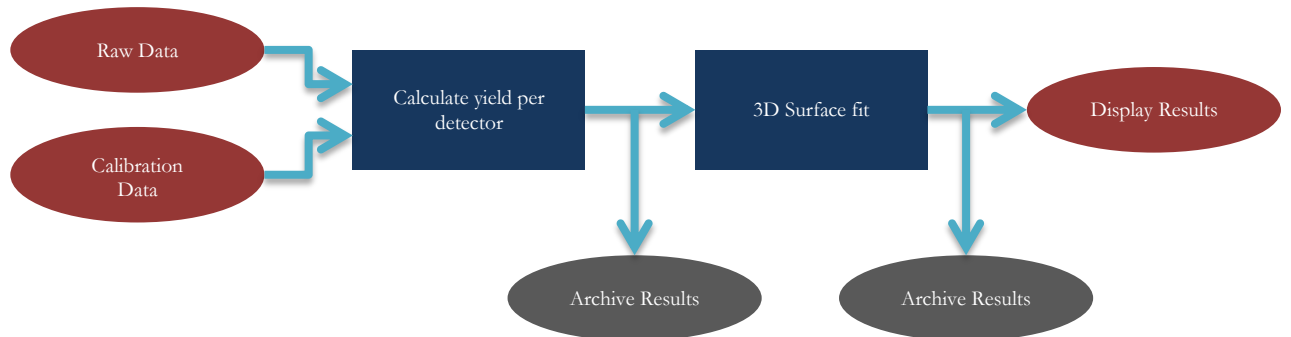


Figure 2: Block diagram of FNAD analysis flow

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Discussion/Implications

There are two main implications for the methods and results described in the previous section. The first is that there is a quality-controlled analysis infrastructure in place that will automatically analyze the FNAD data from any experiment for which the FNAD detectors were collecting data. This reduces human error, increases analysis efficiency, and allows for multiple users to view results in a common web location.

The second implication occurs in the physics domain and arises from the results themselves. The fusion experiments currently being conducted at the NIF require that the target implodes symmetrically. When asymmetries arise, one result is that the target moves with a certain velocity during the experiment. Scientists here at NIF use the 3D neutron distribution as a way to estimate or at a minimum confirm any velocity components. The FNAD results will aid in helping the fusion scientists improve upon future experimental designs.

Personal Experiences

I heard from classmates how their coop experience changed their life, for good or for bad. In my case, this coop has been the most enriching and challenging experience affecting both my personal and professional life, my networking abilities, my financial status, and my mental/physical health.

Firstly, I'm the only intern on a team composed of engineers that have at least 6 years of experience in the field and, at least, an engineering MS. Reality hit when my mentor, Essex Bond, described my new project using a lot of technical terms that were new for me. I've met a lot of amazing professionals that work every day for a common programmatic goal, developing new technologies.

It was challenging to realize that technical papers and internet resources were only partially useful for the signal processing analysis I was doing. I also did not realize the importance of computer science in my field. Three quarters of my signal processing task was finished one month into the coop. Since then, all my work was as a computer scientist consisting in the creation of production software, which I found to be very difficult and tedious.

In conclusion, this isn't just a summer job at the supermarket; it's my first job as engineer. Also, it's my first experience outside of Puerto Rico for 6 months without any family member or people that I already know. At first, it was very intimidating working in a national laboratory research environment with so many experienced professionals, but with my mentor, my newly found friends, and my family's support, I proved to myself that I can be an engineer.